Bistatic Underwater Optical Imaging Using AUVs

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LONG-TERM GOALS

Identification of mine like contacts (MLCs) as either mines or non-mines remains an important step in mine countermeasures (MCM) operations. Optical imagery is the "gold standard" for identification since, with good quality imagery, it allows unambiguous identification of MLCs as either mines or non-mines.

The apparent utility of autonomous underwater vehicles (AUVs) for MCM operations is quite appealing, especially if the AUVs are small, low cost, and provide high quality data. A long range goal to the use of AUVs for MCM operations is to equip such AUVs with small, low cost optical sensors capable of providing identification quality optical imagery.

OBJECTIVES

To be optimally useful, optical sensors designed and developed for AUVs should be small and should require minimal power. In addition, they should be low cost, since the AUV systems themselves must be low cost, and because the AUV might not always be recoverable. Never-the-less, they should provide imagery of sufficient quality to fulfill the crucial identification role in MCM.

Identification quality imaging sensors, such as Streak Tube Imaging Lidar (STIL) and Laser Line Scan (LLS), have been developed for larger MCM platforms. These sensor systems are currently relatively large, expensive, and draw significant power, and so are not immediate candidates for small AUV platforms. These sophisticated sensor systems, however, have been specifically designed to effectively deal with the backscatter noise and blur/glow/forward scatter noise which typically limit the performance of underwater optical sensors.

The thrust of the current effort is to investigate the optical sensor concepts which are designed to exploit the cooperative behavior between small AUVs, or between an AUV and a larger platform. Specifically, by exploiting cooperative behavior, optical sensor systems can utilize bistatic imaging approaches. Bistatic imaging can be anticipated to provide major reductions in the backscatter noise which frequently limits the performance of low cost optical sensor systems. Since the bistatic aspect is the most fundamental change from other existing optical imaging sensors, this bistatic aspect – along with the required cooperative behavior – is the central thrust of the current effort.

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APPROACH

The technical approach of this project is based upon 3 primary elements: 1) concept development, 2) analysis of the concepts developed, and 3) model development to support the concept analysis. An adjunct element consists of analysis of appropriate available data to support the concept development and analysis. This approach is guided by the well established principals which govern the performance of underwater imaging systems[see, e.g., 1,2]. According to these principles, performance is limited by backscatter noise and blur/glow forward scatter noise, and, in some cases, ambient light noise and attenuation. These are the primary areas addressed in the modeling and analysis of the bistatic imaging concepts.

WORK COMPLETED

Initial EO concepts for low cost AUVs have been developed. As indicated in the objectives section, the thrust has been on exploiting bistatic imaging architectures in conjunction with cooperative behavior. This can be anticipated to result in significant reductions in backscatter noise. Depending upon the optical architecture chosen, blur/glow/forward scatter noise may or may not be significantly reduced.

One interesting example of an optical architecture which exploits bistatic imagery to reduce backscatter noise and blur/glow/forward scatter noise was published in the early 1990s[3]. A variant of this approach may be promising for the current application, since it is anticipated that a small AUV may approach an MLC significantly closer than larger platforms (which could contain sophisticated sensors such as STIL or LLS).

An initial analysis of appropriate available data has been completed. This analysis has been focused on identifying the factors necessary to include in the modeling and the analysis. This analysis has made it clear that three-dimensional aspects of scenes (including MLCs) must be included. Imagery included in the results section will indicate why this is the case.

Initial modeling goals have been established to support the required analysis. Of course the modeling goals include realistic treatment of all of the effects know to impact underwater image quality – specifically treatment of backscatter noise, blur/glow/forward scatter noise, attenuation, and ambient light effects. A further goal is a realistic treatment of three-dimensional effects. This is required for several reasons. First, as shown in the results section below, the apparent contrast of an object (or an element of an object) is strongly dependent upon aspect. These aspect-related effects can only be properly treated with a full 3D treatment of the objects and the backgrounds. Secondly, small AUVs may be expected to approach MLCs significantly more closely than larger platforms. As a result, the three-dimensional aspects of the targets will be relatively more significant when imaging using a small AUV than from a larger and more distant platform. Finally, with bistatic imaging the three dimensional relationship between the light source and the receiver must be carefully taken into account. Specifically, depending upon the geometry, shadowing may play a key role. In fact, it may turn out that this shadowing is a key property which may be exploited. For all of these reasons, a full three-dimensional model has been established as a key requirement for this analysis.

An initial 3D modeling framework has been established. This framework allows a high resolution treatment of the three dimensional nature of MLC (and other targets) and of the backgrounds. Within this framework, a scene consisting on one or more 3D targets on a 3D background is analytically sliced into subimages corresponding to the elements within the scene specific range bands. The blur/glow/forward scatter noise effects (for example) are treated within each range-slice subimage with beam spread functions and modulation transfer functions appropriate for that specific range. This treatment is applied both with respect to the light source and with respect to the camera. The position and properties of the light source and camera may be independently specified, as is required for modeling bistatic imaging systems. Modeling of the shadowing of the illumination pattern of the light source by the 3D targets and background is included. This is also crucial for accurate modeling an d analysis of bistatic imaging systems. Finally the resulting composite image is constructed from the range-sliced subimages. In all of this modeling, high-fidelity three dimensional geometrical and textural models of the MLCs and backgrounds are used.

This modeling work exploits the parallel processing and 3D capabilities of modern graphics processing units (GPUs) on modern graphics cards. In particular Microsoft DirectX10, along with High Level Shader Language 4.0, is used to offload portions of the processing from the CPU to the GPU.

RESULTS

The importance of a full three dimensional analysis is indicated by the following imagery. The photos below show two MLCs which have been in their environment for two years. As such, they have been “optically aged”. They are essentially encrusted with sediment, such that they have an effective contrast of zero with respect to the background sediment.

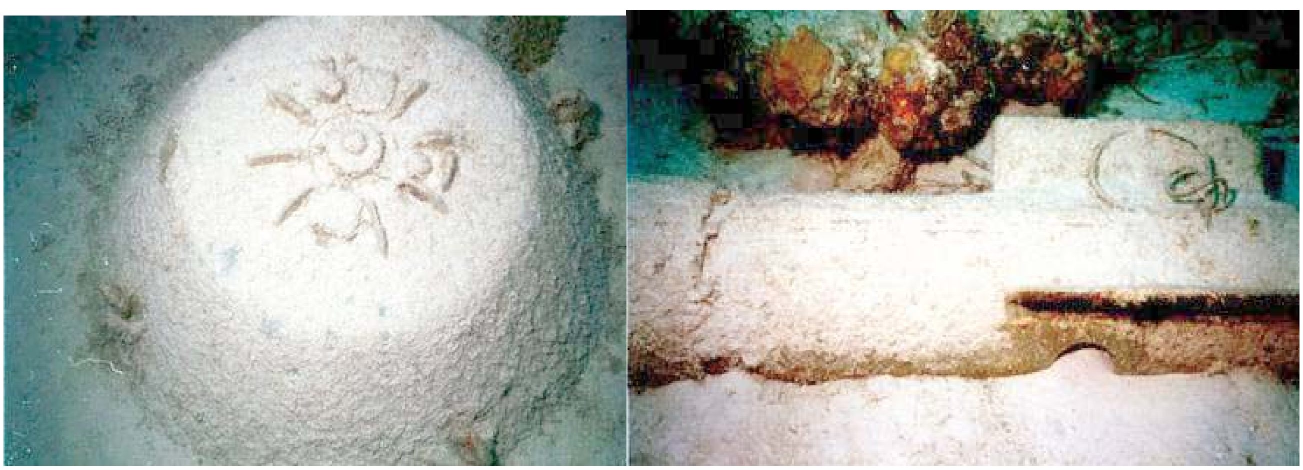

Figure 1. Two photos showing targets which have been in their underwater environment for 2 years. They are encrusted in sediment, and show very little contrast with the sand bottom.

However, the three dimensional nature of the targets results in an effective contrast which is aspect dependent, as illustrated by the imagery below. The image on the left shows enlargments of LLS imagery of these two targets. The aspect dependent nature of their apparent contrast is apparent. The wider angle image on the right is included for context. In addition to the two “optically aged” low contrast targets, the image on the right includes three freshly placed targets. These targets have a much higher contrast with respect to their background since they have not been "optically aged" and are not encrusted with sediment.

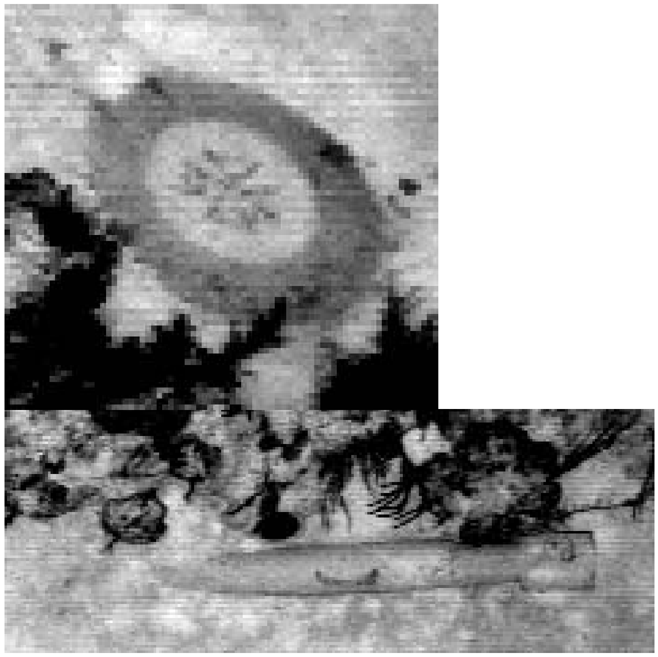

Figure 2. Close-up enlargements of LLS images of the two targets shown in figure 1. The exhibit apparent contrast with respect to the bottom based upon geometrical aspect.

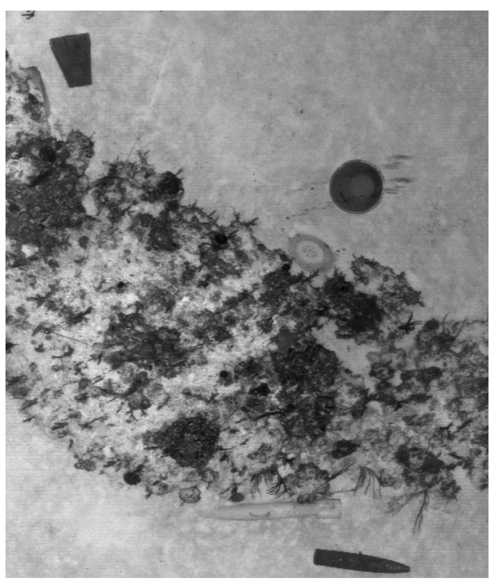

Figure 3. The LLS wide-angle image which includes the two enlargements shown in figure 2. The scene also includes three freshly placed targets which have show much larger contrast (with respect to the bottom) than the optically aged targets. The scene also includes a coral reef.

Initial results from the three dimensional modeling framework are given below.

Figure 4 shows an example of a scene constructed using a high resolution 3D model of a wedge-shaped MLC and a bottom with sand ripples. The modeled blur/glow/forward scatter image of the scene is presented using four different water qualities. In each case the light source has a rectangular beam pattern, and is locate to the upper left of the target. The shadowing due to the target and sand ripples, as well as the texture of the sand, is particularly evident in the clearest water case. As expected, the contrast of these details decrease as the water becomes more turbid.

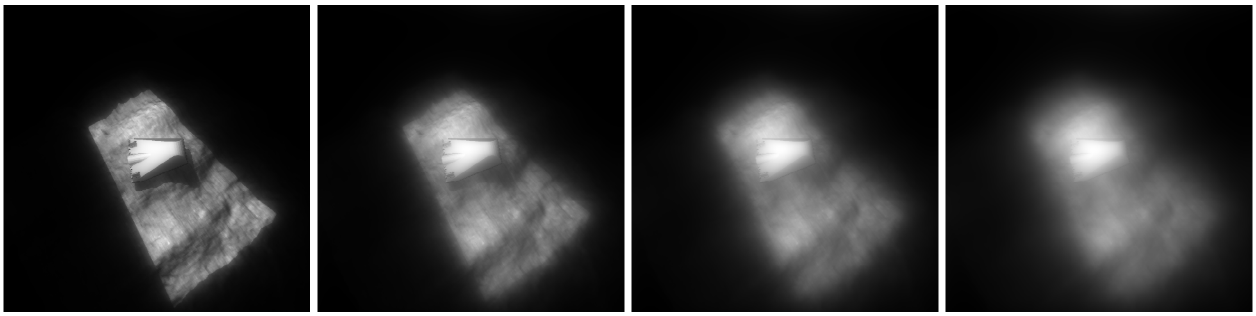

Figure 4. The four subimages present simulated blur/glow/forward scatter images of a wedge-shaped target on a sandy background under four different environmental conditions. Both the camera and the light source are pointing at the target. The camera is looking slightly "ahead", while the light source has a rectangular beam pattern and is located on a second platform above and to the right of the target.

Aspects of the 3D geometry which are independent of water clarity are shown in figure 5. The range from the camera to the scene is represented in figure 5a. Closer objects in the scene are represented by lighter shades. The sand ripples are clearly visible, as is the elevation of the wedge-shaped target above the sand bottom. Because the bottom portion of the image is the lightest, it is evident that the camera is located towards the bottom of the scene, and is looking slightly ahead. Similarly, figure 5b represents the range from the light source to the scene. Because the lightest portion of the scene is in the upper left, it is evident that the light comes from this corner of the scene. 5c represents the region of the sand bottom which would be illuminated by the directional light source. For the purposes of this illustration, the scattering of the light in the water has been neglected. In addition, the shadow cast by the target has been ignored. 5d shows the shadow cast by the target. The shadow is distorted due to the ripples in the sand bottom.

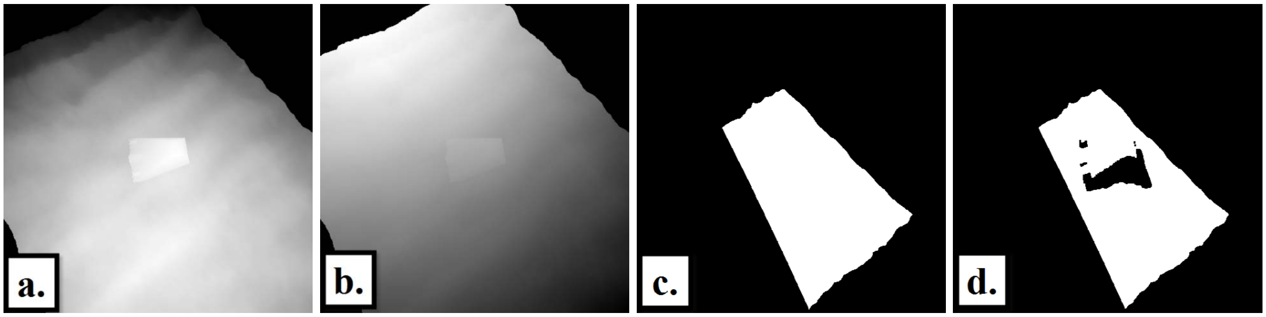

Figure 5. Four different aspects of the 3D geometry are illustrated in the four sub-figures. a) and b) show the range to the bottom (or target) from the camera or the light source, respectively. Lighter shades represent closer objects. The sand ripples are clearly evident, as is the extent of the target above the bottom. a) shows the pattern of the rectangular beam on the bottom in the absence of shadowing by the target and scattering in the water. d) includes the shadowing created by the target in the absence of scattering in the water.

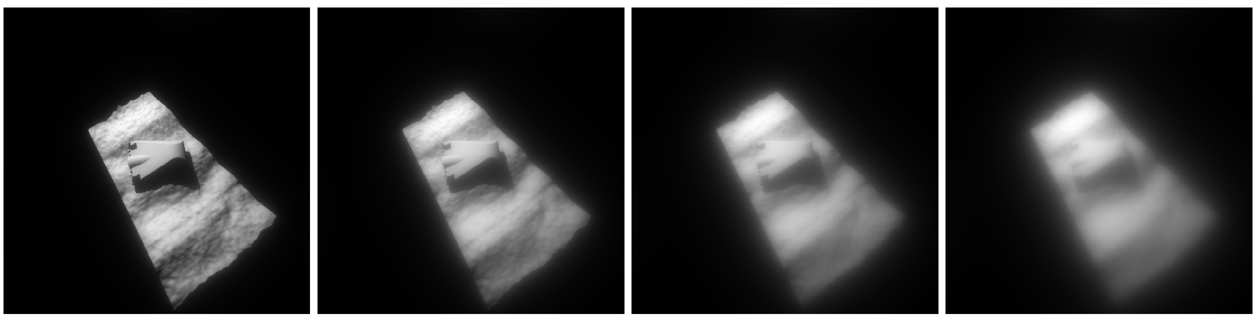

Figure 6. The impact of scattering in the water on the beam illumination pattern for four different water turbidities is represented in the four subfigures.

The impact of scatter on the beam pattern illuminating the bottom, as seen from the perspective of the camera, is shown in figure 6. The four subfigures represent the four different turbidities shown in figure 4. These images include the lambertian factor appropriate to the orientation between the scene surfaces and the propagation direction of the light. These images do not include the inherent reflectance patterns of the scene. The inherent reflectance patterns of the scene are represented by textures. When these inherent reflectance patterns (textures) are included, and the blur/glow/forward scatter associated with propagation of light from the scene to the camera is included, the composite blur/glow/forward scatter images presented in figure 4 are obtained.

An illustration of the range-slicing technique used for the simulations above is shown in figure 7. Figure 7a represents the slicing of the scene into regions based upon range from the camera. Each range-interval slice corresponds to a range of 10 cm. The presence of the sand ripples is clearly evident. Figure 7b represents the blur/glow/forward scatter image of the corresponding range slice for a particular water quality. It is evident that, as required, the more distant range slices are attenuated more strongly than the nearer range slices. When these blur/glow/forward scatter image range slices are summed a composite blur/glow/forward scatter image as shown in figure 4 is obtained. Similar range-slicing is used to model the propagation of light from the source to the bottom and target.

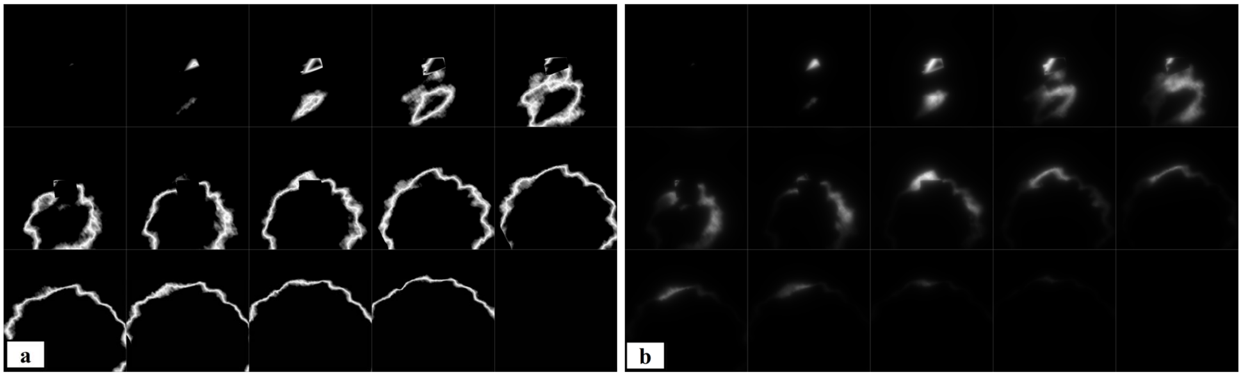

Figure 7. a) shows the results of slicing the scene into 10 cm range intervals. b) shows the blur/glow/forward scatter images of the corresponding range slice.

To my knowledge, this modeling activity is the first model for an underwater optical sensor which utilizes high resolution three dimensional models of targets and backgrounds. As such, this represents a new capability.

IMPACT/APPLICATIONS

The development of optical architectures appropriate to AUVs which exploit cooperative behavior (through bistatic or other approaches) to provide a robust MLC identification capability could add an important capability to these vehicles.

The development of an underwater optical model which includes accurate modeling of three dimensional aspects of targets and backgrounds will add an important level of fidelity to such models. It could form the basis, for example, for an accurate model for the ROAR system.

RELATED PROJECTS

The underwater images shown in figures 1-3 were acquired under the CoBOP project.

REFERENCES

[1] Jaffee, J. S., J. McLean, M. P. Strand, and K. D. Moore. 2001. Underwater optical imaging: Status and prospectus. Oceanogr. 14: 64–75.

[2] M. P. Strand. Underwater electro-optical system for mine identification. 1995. SPIE 2496, p487-497.

[3] Austin, R. W., S. Q. Duntley, R. L. Ensminger, T. J. Petzold, R. C. Smith, 1991. An Underwater Laser Scanning System. SPIE 1537, p57-73.